# research review

OAR: The Research Agency
of The United States Air Force

VOLUME IV NUMBER 1 MARCH 1965


## BASIC MECHANISMS OF COMBUSTION INSTABILITY


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"Oscillatory Combustion" or "Combustion Instability" is undoubtedly one of the major handicaps to the reliable and efficient operation of present-day rocket sytems, as well as in the solution of "scaling" problems for future terresterial and space applications. Many times, the pressures and accompanying temperatures and rates of heat transfer associated with this phenomenon reach such levels that they adversely affect engine efficiency, and ultimately result in the breakdown of the engine through mechanical or thermal failure of the structure.

A great deal of work has been done on this problem in the past decade; but no satisfactory theory has yet been formulated for the basic mechanisms responsible for the various oscillation phenomena. Progress thus far has led only to certain rough rules which act as guides in the design stages of rocket motors. Rocket engines must still be tested for stability before actual final test runs; and if they are found to operate unstably, resort must be had to engineering fixes to achieve stable operation.

Needed still is additional information which will improve our understanding of the phenomenon of combustion-pressure oscillations, which will provide the designer with a priori design criteria for predicting conditions for stable operation (including "scaling" rules applicable to both small and large engines), and which will indicate procedures for attenuating undesirable combustion-pressure oscillations.

To obtain a better understanding of the combustion-instability phenomenon, in a research program supported by AFOSR under Contract AF49(638)-1354, Professor T. Y. Toong of M.I.T. has been studying the triggering mechanisms which lead to the onset of acoustic oscillations in a combustor, and the interactions of these acoustic oscillations with the triggering mechanisms--to determine whether the acoustic oscillations once triggered would amplify or suppress the triggering mechanisms, thus resulting in unstable or stable but rough combustion.

Experiments performed demonstrate that strong interactions between acoustic and flame oscillations can exist through flow oscillations, and that these interactions are due to energy transport between various oscillation modes through both linear and nonlinear couplings.

Through the linear mechanism, acoustic oscillations of a given frequency can be triggered and amplified by flame oscillations

and associated flow oscillations of the same frequency, if proper phase relationships exist as indicated by the Rayleigh criterion. On the other hand, energy transport is possible between oscillations of different frequencies through nonlinear mechanisms that lead to ultraharmonic resonance, subharmonic resonance and synchronization, thus resulting in amplification or suppression (depending on the direction of the energy transport). Test results have also been obtained, showing the expected increasing importance of the nonlinear effects as the amplitudes involved are augmented through imposed acoustic excitation by means of a loudspeaker.

With imposed acoustic excitation, in contrast to the results predicted by the Rayleigh criterion for the linear mechanism, the acoustic waves are amplified when the flames are near the pressure nodes, whereas they are suppressed when the flames are near the pressure antinodes, thus suggesting that a mechanism other than the linear one is predominant. Evidence is available to support the belief that this new mechanism is a nonlinear one.

The intensity of the acoustic-flame interactions can be altered by varying flow velocity through an organ pipe. Under reduced-flow conditions, the linear coupling is eliminated and the flame exhibits regular self-sustained oscillations, just like those observed in a large chamber, where the acoustic interactions are rather weak. However, with imposed acoustic excitation of sufficiently large amplitude, the interactions again become important due to nonlinear effects. Nonlinear coupling between longitudinal acoustic oscillations and tangential or radial flow and flame oscillations has also been observed.

Critical experiments have been conducted to show that the onset of the above-mentioned self-sustained oscillations of diffusion flames is due to the instability of travelling Tollmien-Schlichting disturbance waves--the same


# research review
## OFFICE OF AEROSPACE RESEARCH

OAR RESEARCH REVIEW is published monthly by the Office of Scientific and Technical Information (RRYC), Hq Office of Aerospace Research, USAF, 4th and Independence Avenue, S.W., Washington, D.C. 20333. The objective of this publication is to make a positive contribution to the exchange of information concerning Air Force conducted and sponsored research activities. Individuals or organizations interested in or associated with research may obtain copies without charge by written request to the above address.



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*JACOB SEIDEN*
*Editor*

mechanism which leads to the onset of transition from laminar to turbulent flows. The effects of changes in a flow field, due to the presence of interacting burning and nonburning simulated fuel droplets, on oscillation characteristics can be interpreted in terms of the postulated mechanism of boundary-layer instability. Under some conditions, oscillations can actually be stopped by placing nonburning cylinders near an (otherwise) oscillating flame.

Both theoretical and experimental investigations are in progress to study in detail the nature of the acoustic, flame and flow oscillations, and the energy-transport processes between various modes of oscillation due to both linear and nonlinear couplings. It is hoped that engineering solutions to either control or eliminate unstable combustion in rocket motors, for example, can be obtained through an understanding of these basic instability mechanisms. ★

# radar wind-velocity-measurement technique

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A new radar technique for measuring wind velocities in cloud systems has been developed by AFCRL. The technique may be used with conventional radar equipment after only slight modification of the antenna, thus providing a wind-measuring capability to radars which could previously observe only storm patterns. The method provides a "pseudo"-Doppler capability without the complexity and cost of a conventional Doppler radar.

This method makes use of two beams squinted slightly to either side of the antenna bore sight axis. The bore sight axis is directed perpendicular to the direction of the wind so that the right beam is pointing slightly upwind, and the left beam slightly downwind. Precipitation echoes in the right beam produce a small positive Doppler frequency shift proportional to the upwind component, while those in the left beam produce an equal and opposite Doppler shift. Since the radar is incoherent, neither Doppler component can be measured. But since the echoes from both beams arrive at the common receiver synchronously, they beat with one another to produce a fluctuating echo whose amplitude fluctuates with a frequency which is twice the Doppler frequency. Thus, the fluctuation is a unique measure of the cross wind. (This may be recognized as a version of the Janus-type Doppler navigator.)

Of course, things are not as simple as the above description implies. Because of the finite width of each beam, each will produce a spectrum of Doppler frequencies proportional to the beam width. Moreover, the spectrum will be broadened by contaminating effects such as turbulence and wind shear. As a result, the beating of the echoes from the two beams will produce not a single fluctuation frequency, but a spectrum of such frequencies. When the spectrum is analyzed, we find that it has a well-defined peak at the frequency corresponding to the thin beam case. Fortunately, it is not necessary to analyze the entire spectrum, but only to measure its root mean square (RMS) frequency. The difference between the RMS fluctuation frequency on the two beams from that on either one of the beams is then a unique measure of the wind speed, and is independent of both the beam width and the contaminating influences.

Obviously, the beams cannot be separated too greatly; otherwise a storm of limited extent may not occupy both beams simultaneously. Since the upwind and downwind Doppler components are therefore small, the accuracy of the method decreases with low wind speeds. However, it is particularly well suited to the measurement of hurricane winds, and has been recommended to the Air Weather Service for their use in hurricane reconnaissance. AFCRL is now assembling equipment to test the method.

When used on a Doppler radar with a third axial beam, the axial beam would measure the wind component along its axis, while the two squinted beams would measure the perpendicular component. In this way, the complete wind vector can be measured at each and every point in space. ★

## *AFOSR Cloudcroft Seminar*

The Air Force Office of Scientific Research (AFOSR), Office of Aerospace Research, will hold its Tenth Anniversary AFOSR Summer Scientific Seminar at Cloudcroft, New Mexico, 14-25 June 1965. The theme of the seminar will be "Science in the Sixties," an examination of central questions in a number of scientific disciplines at midpoint in the decade. Sixteen leading scientists, many of whom are AFOSR grantees, will participate in the seminar and informal sessions, providing a comprehensive assessment of current understanding as well as trends of future development throughout the fundamental sciences.

The seminar will be held with the cooperation of the University of New Mexico and the Missile Development Center, Air Force Systems Command, Holloman AFB, New Mexico. Armed services' scientists and engineers, both military and civilian, are eligible to attend. Of the 169 persons attending the 1964 conference, 60 were officers and the balance were civilians. The officers included 28 on active duty and 32 reserve officers on training duty from the Air Force, Army and Navy.

Additional information on the 1965 seminar is available from:

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# RESOLUTION OF MICROWAVE ANTENNAS

### MICROWAVE PHYSICS LABORATORY
### AFCRL

Conventional microwave radar antennas are capable of better performance--better imaging and resolution--than the performance predicted by classical resolution criteria. Antenna designers have known this for some time, but few studies have been undertaken to explain why.

Such a study was recently completed by Charles J. Drane, Jr., and John F. McIlvenna of AFCRL. In their study, they substituted certain concepts of communications theory for traditional radiation pattern analysis. A fresh perspective on the problem was thus gained. While the adaption of communications-theory concepts to antenna analysis is not a new idea, the AFCRL study marks its first application to resolution problems associated with airborne radar mapping.

When viewed as a communications-theory problem, we see that antenna and optical systems are similar in the sense that the microwave antenna and the optical lens system are both imaging systems in which image quality and resolution are basic considerations. Both can be treated as low pass spatial frequency filters characterized by a transfer function.

"Spatial" frequency and the transfer function, as key aspects of the AFCRL analysis, should be explained. A general antenna object or target, spatially distributed, can be considered by Fourier analysis to be decomposed into a set of sinusoidal variations in space, of specific amplitudes and spatial frequency. The transfer function concept, widely used in optics, specifies which spatial frequency components in the object spectrum will be passed by the antenna and how much distortion each component will incur as it passes through the system. The transfer function can be determined directly from the aperture distribution of the antenna.

The AFCRL study was centered on the use of transfer function techniques to analyze the mapping of ground targets by an airborne radar. The traditional approach to evaluating antenna resolving power has been based on the Rayleigh two-point criterion, defined in terms of a specific separation between two isolated point targets. This distance also bears a direct relationship to the beam width of an antenna. According to this classical criterion, detail sizes, in an extended object, smaller than this Rayleigh distance will not be reproduced--that is, resolved--by the antenna. In actual mapping operations, however, detail sizes much smaller have been resolved.

The AFCRL investigation indicates that, for certain kinds of extended, man-made ground targets--airfields, railroad yards and military complexes--image quality and resolution can be very much independent of the radiation pattern used to map them. This result is seen quite readily when antenna resolution capabilities are re-examined in terms of the transfer function.

From the standpoint of aerial reconnaissance, all objects in the antenna's field of view, other than targets of interest, represent so much clutter--or spatial noise. As a part of the AFCRL study, an attempt was made to measure image degradation as a function of the amount, type, frequency content and spatial extent of various types of spatial noise. An understanding of these relationships may provide a means for prescribing effective radar camouflage measures. ★

# HIGH-VOLTAGE DC TRANSMISSION THROUGH THE EARTH: A STUDY OF EFFECTS

MICROWAVE PHYSICS LABORATORY, AFCRL

What would be some of the effects of passing high-voltage currents in the 400-ampere range through the earth between electrodes separated by several hundred miles? Would the currents interfere with railway-track signaling circuits?--would ground currents influence aircraft compasses or radio aids to navigation?--would there be danger to animals or persons?

Arnold Orange of AFCRL, together with representatives of the Bonneville Power Administration, Portland, Oregon, and scientists from Geoscience, Inc., of Cambridge, Mass., have recently reported on experiments designed to answer these questions. Orange was asked to participate in the study because of his unique knowledge of the earth's crust as a signal-carrying medium. The study was an outgrowth of a proposal for tying together the power networks of the Pacific Northwest and the Southwest, using high-voltage, direct-current transmission instead of alternating current.

An advantage of direct current, not possessed by alternating current, is that one half the rated power of a line can be transmitted with one conductor out of service by allowing the current in the remaining conductor to return through the earth. Before adopting this scheme, however, it was necessary to bring to light any possible harmful effects of the ground current flow. A series of tests were conducted in the Columbia Basin for this purpose. In these tests, currents of from 90 to 400 amperes were passed through the earth between electrodes separated by 40 to 240 miles. Surface potential gradients were measured at varying distances from the current electrodes. Measurements of change in pipe to soil and railroad-track potentials were also made.

As a result of these tests, it appears that high-voltage direct current will not interfere with railway-track signaling circuits, or with aircraft compasses or radio aids to navigation. By using proper electrode size, voltage gradients--even at the electrode itself--will be below levels of possible danger to persons or animals.

Corrosion damage to buried metals, such as pipe lines, does present a problem. But if electrodes are located as far as practical from buried metal structures, or if the structures themselves are specially protected, the problem can be avoided. Direct-current leakage through metallic circuits of grounded a-c systems also appears to present no problems. The tests in the Columbia Basin are the first in a series of field tests that may be necessary before plans are made final.

Orange's contributions to the Bonneville Power Administration study are a direct result of his research at AFCRL over the past several years (as reported in the 8 January 1965 issue of Science) concerned with signal propagation through the earth's crust. By such means, extremely hardened communications can be achieved for distances between 10 and 50 miles. NORAD has recently evidenced considerable enthusiasm for the potential operational capabilities of the technique. ★

# puzzle patterns processed into pictures
## (problem in pattern recognition)

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The problem of pattern recognition by means other than the eye and brain has not been solved. Command and Control systems could effectively utilize automated methods. Dr. Herbert Freeman of New York University's Laboratory for Electroscience Research has been working on automated procedure for curve analysis and recognition under an AFOSR grant.

During the past year, Dr. Freeman demonstrated a computer program which is capable of assembling jigsaw puzzles by using only the shape of the pieces. This demonstration is the culmination of an investigation into curve matching. Also investigated was digital encoding of contour data so that errors due to this transformation are predictable and minimal.

One of the main features of this program is the curve-correlation algorithm which matches curve segments. This algorithm operates on curve-representation data which is independent of the curve's orientation on its original map. It is also independent of the scale used to encode the curve. This has been one of the major problems in character recognition. Dr. Freeman's work now makes it possible to analyze curve segments without regard to size rotation or translation.

Dr. Freeman has been using a large-scale computer, so that immediate application to character reading is not practical; but this work is a major step in that direction. The computer, by using the jigsaw puzzle, was able to take the encoded data which describe the shapes of the pieces of the jigsaw puzzle, assign these to their proper places, and then print out on the X, Y plotter a picture of the completed puzzle. The computer worked at this task much like a human being by twisting and matching various portions of the pieces' edges until a fit was secured.

Although solving jigsaw puzzles is not a major mission of the Air Force, analyzing pictures, maps and visual displays is a part of all Command and Control systems. Computer interpretation of visually displayed data is important. However, we have not yet arrived at the point where a computer in the control tower can direct aircraft movements by reading TV tubes; but we are heading in that direction.

Dr. Freeman is conduting further research in this field. He is presently expanding his techniques to three-dimensional space and contour-map recognition and assembly. Now, all we need is a three-dimensional TV tube.

*REFERENCE*

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# NEW BALLOON MATERIAL

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A goal of balloon research is to take the heaviest possible pay load to the highest possible altitude with a balloon of the smallest possible volume. The approach to this goal is obvious. It is to develop balloon materials with high strength-to-weight ratio. On 5 December 1964, from its balloon-launch facility at Chico, California, AFCRL took a long stride toward this goal. It successfully demonstrated the suitability of a new extremely lightweight balloon fabric--a fabric that appears to be far superior to any balloon material used in the past.

This new material, consisting of two layers of .00014-inch-thick polyethylene reinforced with a network of fine (70 denier) nylon filaments, is equivalent in weight to 1/3-mil thickness polyethylene, while possessing the tensile strength of 2-mil thickness polyethylene.

We see the potential of the new lightweight material when we compare it with 1/2-mil polyethylene. To send a 25-pound pay load to 150,000 feet using 1/2-mil poly-

ethylene would require a balloon volume of 6 million cubic feet with a fabric weight of 550 pounds, as against a volume of 1.5 million cubic feet and a weight of only 119 pounds for the new fabric.

The December flight carried a 275-pound pay load to an altitude of 95,000 feet. It was the first of several flights designed to test the new fabric. ★

# ozone absorption spectrum between 8.5 & 10 microns

## OPTICAL PHYSICS LABORATORY, AFCRL

The general nature of the ozone absorption spectrum between 8.5 and 10 microns has been known for some time, but the details of the spectrum in this region have not previously been explained. As a consequence, the constants have remained poorly determined.

Shepard A. Clough and Francis X. Kneizys of AFCRL have completed research leading to the establishment of essential constants. Two factors contributed to a solution of this problem: 1) the availability of spectra of exceptional quality taken on the high-resolution spectrometer of the Optical Physics Laboratory, AFCRL; and 2) the extensive use of high-speed digital computers to handle the otherwise unmanageable computational work involved in the analysis of a vibration-rotation band of an asymmetric molecule of this type. Approximately 4,000 individual rotational lines contribute to the spectrum, and the frequencies and intensities of these lines must be accurately computed.

Although there are two vibration bands contributing to the spectrum in this region, one considerably stronger than the other, it has been found that there is a strong interaction between the two. This interaction leads to serious intensity anomalies in the weaker band and in fact forms the salient features of that band. Using the constants obtained in this study, it has been possible to compute theoretical absorption contours which agree with the observed contours to well within error limits.

# MECHANICS OF BLOOD VESSELS

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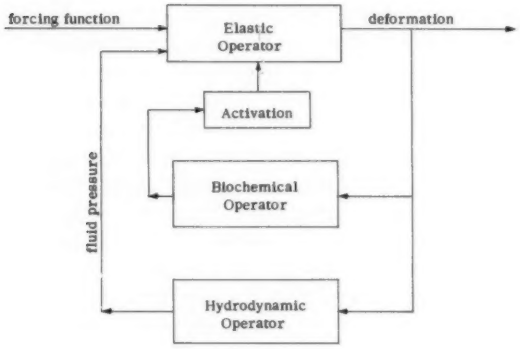
To gain deeper insight into continuum mechanics, the mechanical behavior of living organs is being explored by the AFOSR-sponsored aerospace scientist, Professor Y. C. Fung of the California Institute of Technology. The reasons for this study are many. In the first place, the subject is of intrinsic value to health and welfare in general, and to aero- and space medicine in particular. In the second place, living organs differ in many respects from the usual materials considered in engineering, so that their study may reveal as many critical areas as possible of the usual theories of continuum mechanics. Furthermore, of primary importance is the fact that, since the research is being carried out by an active aerospace-mechanics-oriented scientist, it is expected that significant contributions will be made to such diverse areas as the explosive forming of thin shells, the design of polymerized space structures made by gradual blowing and hardening in space, fluid control theory, and the science of rheology.

In the initial stage of these investigations, the cardiovascular area is under examination. It may be noted that the action of the heart and the blood circulation may be analyzed with the concept of "functional operators" which was introduced by Professor Fung into the theory of aeroelasticity. (1) For example, consider the artery. The whole system is representable as a set of interconnected functional operators as shown in the figure below. The artery, as an elastic operator, yields a certain deformation when known forces and fluid pressure are applied. The hydrodynamic operator yields fluid-pressure distribution when known fluid influx and elastic deformation are specified. The biochemical operator responds to the deformation history and creates a biochemical potential which may control the elastic or viscoelastic properties of the artery.

These operators are interconnected. The behavior of the entire system can be very complicated and, because of internal feedback, the relationship between the input and output of the entire system will be nonlinear in general. The elastic and hydrodynamic operators are common in ordinary aeroelasticity. The biochemical operator is analogous to the automatic control circuit in airplane dynamics.




This conceptually simple analysis reduces a complex problem to a series of simpler problems. Each of these operators can be studied separately. The more thoroughly we understand each operator, the better we can analyze the whole system.

Professor Fung has maintained close cooperation with the physiologists and biorheologists on the California Institute of Technology engineering faculty, and at the Loma Linda University Cardiovascular Research Laboratory. He helped Dr. W. Frasher of the Loma Linda University analyze the results of a study in the dynamic properties of pulmonary arteries. In a series of experiments, Dr. Frasher isolated a segment of the pulmonary artery of a dog, in vivo, and injected a fluid of controlled quantity according to a preset history. The purpose was to see if the viscoelastic character of the pulmonary-artery wall is significant, i.e., whether the stress in the artery wall depended on both the strain and rate of strain of the wall material. Analytically, the problem resembles classical aeroelasticity. The main difference lies in the large strain that inevitably occurs in the biological experiment. However, once large strain is introduced, classical linear elasticity theory becomes inapplicable. Furthermore, the flow is such that viscosity cannot be ignored. These considerations imply that an extensive widening of the classical theories of elasticity, hydrodynamics, and aeroelasticity is necessary in order to put biomechanical research on a firm foundation. Fortunately, the study of the pulmonary-artery dynamics led to the conclusion that the viscoelastic feature of these blood vessels is relatively unimportant so far as physiological rates of changes are concerned. Hence, the artery-wall material can be treated as an elastic material in large strain.

A program is currently under way to measure the elastic properties of arteries and veins in the finite strain regime. In this program, a segment of these vessels will be subjected to axial tension and internal pressure. The deformation will be recorded photographically. The data will be analyzed according to the finite strain theory to determine the strain energy function of these vessels in living conditions.

It may be pointed out that a precise knowledge of the elastic properties of blood vessels is important both from a basic physiological point of view, and from an aeromedical point of view. Precise elastic data are required for further analysis of blood flow, and of wave propagation in the blood-vessel wall. These data are also vital in the problem of finding artificial vessels to replace sick, hardened, or clogged blood vessels. At the present time, such precise data do not exist.

As a theoretical foundation to this experiment, a detailed analysis of the large elastic deformation of cylindrical tubes was made. The theory was tested in the laboratory by measurements of latex rubber tubes, and good agreement was obtained. A part of the analysis and comparison with experiment are presented in AFOSR Scientific Report 64-2020. (2) ★

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*(2) Lee, J. S., "Large Elastic Deformation of Thin Cylindrical Tubes," AFOSR Scientific Report 64-2020, October 1964.*

# the capture of TORO

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The first chapter in the saga of the capture of Toro begins at the Lick Observatory. It was in 1948 when C. A. Wirtanen determined that the streak of light on a photographic plate was a previously unknown planetoid. He called it 1948-OA. (Minor planets, asteroids, or planetoids are bodies resembling planets. Most of the thousands of planetoids are in orbit between Mars and Jupiter, where they are believed by many to be the remains of a large planet that once traveled the same path.)

The second chapter took place in 1956 when more observations were made on what was thought to be 1948-OA. The last and final chapter occurred in 1964 when 1948-OA was captured and named Toro. The capture and naming were accomplished by Professor Samuel Herrick and his research assistant, Kenneth Ford, of UCLA. Working with equations, painstaking calculations, and the observations made in 1948 and 1956 on the planetoid, 1948-OA, they predicted where it could be found in 1964. These tasks were completed with such exactness that Dr. Elizabeth Roemer of the U.S. Naval Observatory in Flagstaff, Arizona, found the tiny visitor on July 2, 1964 within 11 seconds-of-arc of its predicted place, that is, within the length of a man's forefinger when seen a mile away.

There are now approximately 1,650 planetoids in captivity. These are minor planets that have been named, and whose solar orbits have been accurately determined. After a planetoid is discovered on a photograph, it is given a number and letter designation that indicates the year and month it was first observed, as was done with Toro.

When three observations have been made, it is possible for astronomers like Professor Herrick to obtain a preliminary orbit. After this orbit has been proved out, the minor planet's provisional number is discarded and it is named, usually by its original discoverer. (Mr. Wirtanen graciously waived a discoverer's prerogative because of the planetoid's phenomenal prediction and recapture. Dr. Herrick then named it Toro, after his wife's maiden name.) It is then considered a permanent captive.

Although the hunting of minor planets and the science of celestial mechanics have their own purposes and fascinations, Professor Herrick has found them to be of great value as a testing ground for the development of highly reliable, accurate, and foolproof techniques to forecast and control the paths of man-launched vehicles in space. (The development of the theory which was used to predict the path of Toro was supported by AFOSR as part of a research program with Professor Herrick entitled, "High Precision Geocentric Interplanetary Orbits.") ★

# A NEW TYPE OF LIQUID IMMISCIBILITY

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Anyone who has seen an oil film on water is familiar with the phenomenon of liquid immiscibility. Any good bartender knows that many liquids mix completely to form a single liquid. However, it is not unusual for a second liquid not to dissolve in the first liquid, but rather to settle in a layer on top or underneath the first liquid. This inability to mix is known as liquid immiscibility, and is the basis for the preparation of several technologically important materials. It is also the key to the purification of several metals, and the cause of the formation of many ore deposits. The technologically important high-silica glass Vycor which forms the outer section of the Gemini spacecraft windows can be prepared because of this phenomenon. Intimate mixtures of crystals of such metals as zinc and lead can be sepa-

rated by simply melting the materials. The two metals are almost totally immiscible in the liquid state, and the zinc melt floats on top of the lead and can be skimmed off. If metal-sulfide liquids dissolved in silicate melts, much of the world's ore minerals would be disseminated worthlessly throughout mountains of granite. As it is, the metal-sulfide liquids separate from the rock-forming liquids and crystallize as veins and pockets of valuable ore.

The phase equilibria diagrams plotted from experimental data show the ranges of temperature and composition over which two liquids do not mix. The phase diagram for the hypothetical system A and B in which the liquid phases are totally soluble in each other represents melting relationships of mixtures. A curve formed by connecting the temperatures at which each mixture becomes a single liquid is called the liquidus, and is shown in Figure 1. A smooth liquidus on a phase diagram represents total miscibility of the liquidus in that system. In short, the addition of a second species to a liquid affects the temperature at which crystals of the original material will begin to "freeze out" of that liquid. If, when a second liquid is added to the original liquid, it does not enter the structure of that liquid, it can, of course, have no effect on the freezing temperature. The resulting liquidus curve is shown in Figure 2. If we melt B at temperature $T_1$ and begin adding A to it, A will be dissolved in the liquid up to composition 1, and the freezing point of each mixture between pure B and liquid 1 will be lowered. At point 1, the B-rich liquid is saturated in A and further additions from points 1 to 2 will not enter the liquid and hence will not affect the freezing point; therefore, the liquidus will be flat, or offset, from points 1 to 2. The area above the flattened region of the liquidus is known as a miscibility gap, or an area of liquid immiscibility. Most gaps pinch out with increasing temperature, and the critical point is at the temperature above which the liquids in the system are again completely miscible. A system that exhibits this type of behavior is that of silica-calcium silicate.

Another type of immiscibility has long been recognized. This type, as shown in Figure 3, exhibits immiscibility with increasing temperature, and therefore has a lower critical point. This behavior is shown by the system water-triethylamine. The two types of behavior are both possessed by the liquids in the system nicotine-water. As shown in Figure 4, the system has both a lower and an upper critical point.

Still another type of liquid immiscibility has been recognized recently. Work done at the Metallurgy and Ceramics Research Laboratory, ARL, has contributed greatly to the understanding of this newest phenomenon. In 1939, a patent was issued to Hood and Nordberg for the preparation of Vycor glass from a composition that showed two immiscible glass phases. The starting composition was within the ternary oxide system, $Na_2O$-$B_2O_3$-$SiO_2$. However, in 1952, when Morey reported on the phase equilibria of that system, he said he reported no direct evidence for liquid immiscibility. One of the binary systems did, however, show a flattening of the liquidus. It was the system, $SiO_2$-$Na_2B_8O_{13}$. The work at ARL on the polymorphism of silica involved some runs in this system which suggested that there was no flattening in the system. A study of the liquidus revealed a continuous S-shaped curve. Many recent studies using the electron microscope have revealed that two glass phases do exist in the system, and further, that the separation of the liquids occurred at temperatures which could now be recognized as below the liquidus. Postulating that the immiscibility was a type never reported before, and one which occurred as a metastable subliquidus type, the group at ARL set out to look for such a miscibility gap. The data proved the theory to be correct, and Figure 5 is a sketch of the new diagram for the system with the elusive immiscibility gap located.

Having shown the nature of this phenomenon, it is believed by the workers at ARL that other systems may exhibit the same behavior. The clue to its existence can be found in the S-shape of the liquidus. It is possible that new materials and new processes will result from the recognition of this type of immiscibility in systems other than the system, silica-sodium tetraborate.

Fig. 1

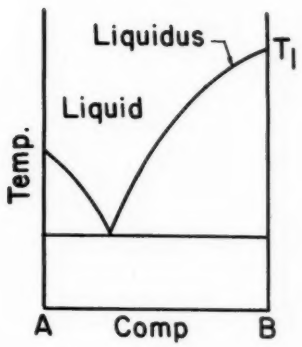
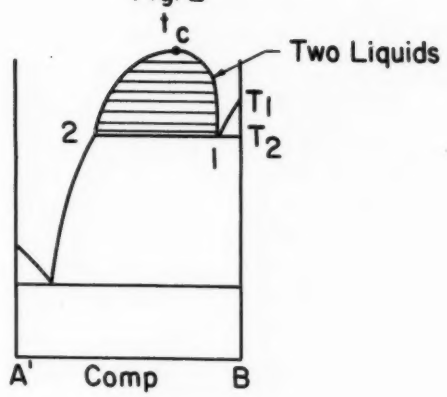



Fig. 2



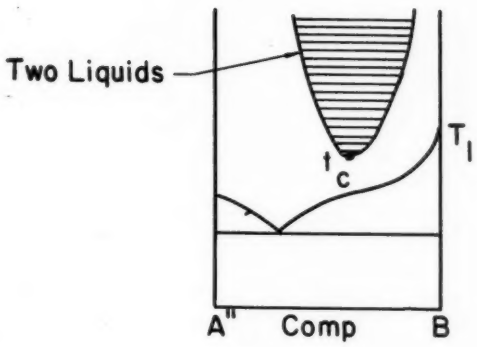




Fig. 3

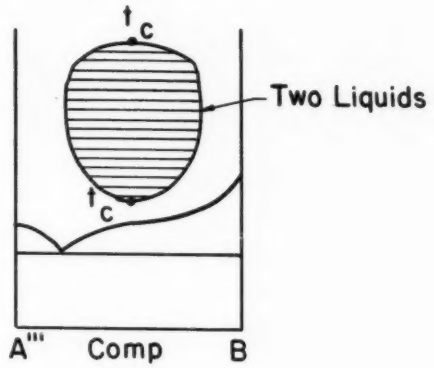



Fig. 4

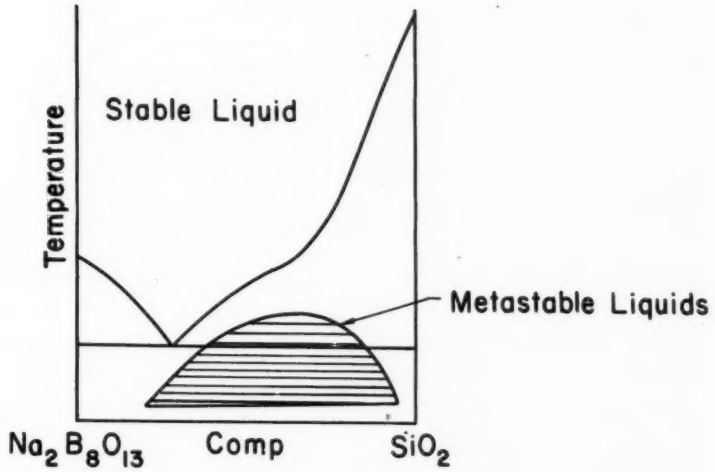
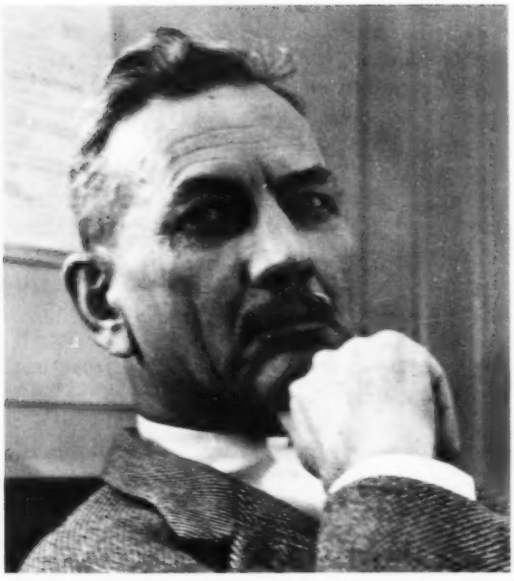


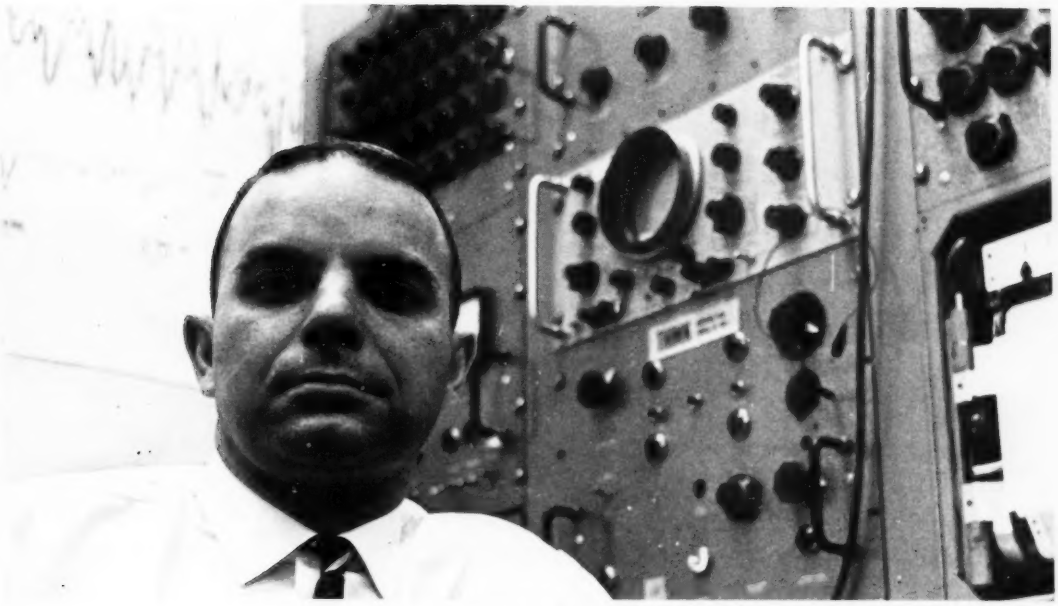

Fig. 5



# PROFILES

*Dr. Norman A. Haskell, a senior scientist with the Wave Propagation Branch, Terrestrial Sciences Laboratory, AFCRL, writes in this Review on "Extracting Nuclear-Induced Signals from Seismic Noise." He has been with AFCRL since 1948. During that time, he has worked in the fields of atmospheric acoustics, air blast phenomena, and seismology. His current research is related to the long-range detection of underground nuclear explosions by seismic methods. Dr. Haskell has a B.S. in Mining Engineering, magna cum laude, from the Harvard University Engineering School (1927). He also has an M.A. in Geology (1935), and a Ph.D. in Geology (1936), both from Harvard University. Before he joined AFCRL, he was Chief Geophysicist of the U.S. Smelting, Refining and Mining Company from 1946-1948. He has a number of publications to his credit, and is a member of several professional societies, including Tau Beta Pi, American Physical Society and others.*

*Mr. James C. Payne, an aerospace engineer with the Balloon Research Branch, Aerospace Instrumentation Laboratory, AFCRL, has concentrated his main effort on developing an air launchable balloon system which would be used to track and evaluate the intensity of hurricanes in the North Atlantic hundreds of miles from land. He is presently engaged in the development of thin-film, high-altitude balloons, launch-site support equipment, instrument packaging for high-altitude research balloon flights, and a technique to launch balloons from helicopters. Mr. Payne has a Bachelor of Mechanical Engineering degree from Syracuse University (1950), and is a member of the Massachusetts Society of Professional Engineers. In this Review, he describes a "New Balloon Material."*



*Mr. Shepard A. Clough, a physicist with the Infrared Physics Branch, Optical Physics Laboratory, AFCRL, is currently engaged in the study of molecular physics, using advanced techniques in the field of infrared spectroscopy. He has a Bachelor of Engineering Physics degree from Cornell University (1954) and an M.A. from Columbia University (1958). He has also done work at M.I.T. toward a Ph.D. degree in Physical Chemistry. Mr. Clough has been with AFCRL since 1958. Previous to that, from 1956-1958, he was on active duty as an Air Force officer (physicist) with the same organization. He has a number of publications to his credit. Some of his current work is described in the article, "Ozone Absorption Spectrum between 8.5 and 10 Microns," which appears in this issue of the Review.*

*Dr. Thomas J. Rockett, a research ceramicist with the Metallurgy and Ceramics Research Laboratory, ARL, describes in this issue of the Review a "New Type of Liquid Immiscibility." In his current research on high-temperature phase equilibria, he is investigating the phase relations in the system, $B_2O_3$-$SiO_2$. He is also doing related work on the stable phases of silica, and is conducting an investigation of the system, $GeO_2$-$B_2O_3$. Dr. Rockett has a B.S. in Geology from Tufts University (1956), an M.S. in Geophysics from Boston College (1958), and a Ph.D. in Mineralogy from Ohio State University (1961). In 1962, he received a National Science Foundation postdoctoral fellowship. Dr. Rockett has several publications to his credit.*

# PROFILES

*Current research by Mr. Charles J. Drane, Jr. (left) and Mr. John F. McIlvenna (right) is reported in the article, "Resolution of Microwave Antennas," appearing in this issue of the Review. Both are with the Microwave Interactions and Analysis Branch, Microwave Physics Laboratory, AFCRL, Mr. Drane as a research physicist, and Mr. McIlvenna as an electronic engineer. Mr. Drane has a B.S. in Physics, cum laude, from Boston College (1950), and an M.S. in Physics from M.I.T. (1953). Since coming to AFCRL in 1955, he has worked on the application of techniques of communication theory to antenna design. He has a number of publications to his credit. Mr. McIlvenna has a B.S. in Electrical Engineering from M.I.T. (1962), and is presently studying for his Master's degree. Currently, he is working on the application of communication and information theory techniques to the design of microwave antennas. He has several publications to his credit.*

*Captain James T. Clay, ARL scientist with the Hypersonic Research Laboratory, writes in this issue of the Review on "Dynamic Stability Testing at High Mach Numbers." He has a B.S. degree from the University of Wichita, Kansas (1954), an M.S. from the University of Michigan (1958), and an M.A. from Princeton University (1963). Previously, he had worked as an aerodynamicist with the Hypersonic Flight Section, Flight Dynamics Laboratory, Wright-Patterson AFB, Ohio, and as a preliminary design engineer with the Design Branch, Aircraft Laboratory, Wright-Patterson AFB, Ohio. Captain Clay's current research is in hypersonic gas dynamics.*

# dynamic stability testing at high MACH NUMBERS

CAPTAIN JAMES T. CLAY
Hypersonic Research Laboratory, ARL

Some of the most difficult quantities to measure in a hypersonic wind tunnel are the damping derivatives, $C_{m_q}$ and $C_{m_{\dot{\alpha}}}$, of an oscillating model. In high-enthalpy facilities such as a hot-shot tunnel or a shock tunnel, the run times are so short that only a few cycles of oscillation may be obtained during the period of steady-state flow. This is especially true when the low values of reduced frequency, $\frac{\omega \ell}{V}$, experienced by a full-scale vehicle at high altitudes, are duplicated by the model test.

With only a few cycles to analyze, the damping must be large before accurate results may be obtained; however, in high-Mach-number flows, this is not the case. In fact, the aerodynamic damping is quite low at hypersonic speeds. Therefore, to obtain a sufficient number of cycles for accurate determination of the damping during a run, either the frequency of oscillation must be increased, or the tunnel run time must be increased. The ARL 20-inch Mach-14 hypersonic wind tunnel accomplishes the latter, and is ideally suited to obtain dynamic stability derivatives at high Mach numbers. Although free-flight enthalpy is not simulated, free-flight reduced frequencies are, and several hundred cycles of oscillation may be obtained during a run.

A one-degree-of-freedom, small-amplitude, free-oscillation test rig has been developed at ARL for the study of dynamic stability problems in hypersonic flow. This test rig uses a flexure, (Figure 1), to connect the model to the supporting sting. During a wind-on run, the oscillation frequency is determined by the moment of inertia of the model, the spring constant of the flexure and the aerodynamic stiffness, while the damping is determined by the structural damping (internal friction in the flexure material) and the aerodynamic damping. To separate the

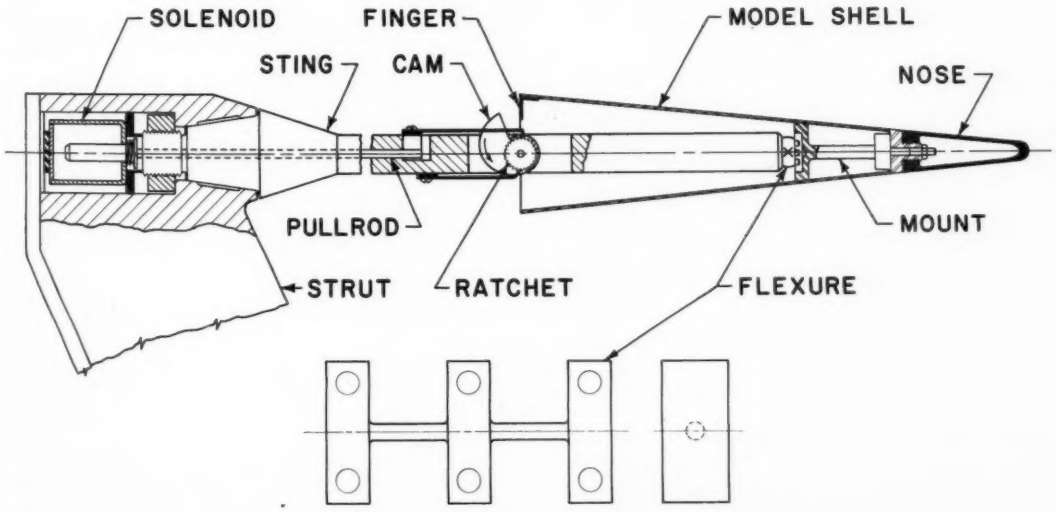



FIGURE 1. Model, Support System and Flexure used for Dynamic Stability Tests.

aerodynamic terms from the structural terms, a wind-off run at near-vacuum conditions must be made. The flexure was designed to have minimum "structural" damping, thereby maximizing the difference between the wind-on damping and the wind-off damping. The reason for maximizing this difference can be illustrated as follows: the motion of a model oscillating in a wind tunnel can be described by the linear second-order ordinary differential equations

$$I\ddot{\alpha} = (M_\alpha - k)\,\alpha + (M_q + M_{\dot{\alpha}} - D)\,\dot{\alpha} \quad \text{(wind on)}$$

$$I\ddot{\alpha} = -k\alpha - D\dot{\alpha} \quad \text{(wind off)}$$

where

$\alpha$ = variation of angle of attack from equilibrium

$-D\dot{\alpha}$ = structural damping moment

$(M_q + M_{\dot{\alpha}})\dot{\alpha}$ = aerodynamic damping moment

$-k\alpha$ = flexure moment

$M_\alpha \alpha$ = aerodynamic restoring moment

$I$ = moment of inertia of model

The above equations can be solved for the aerodynamic damping and the aerodynamic spring constant if the time history of the oscillations is known for wind-on and wind-off conditions, and by using the fact that D is inversely proportional to frequency.

$$M_q + M_{\dot{\alpha}} = -\frac{1}{\pi} I \omega_1 \left[ \delta_1 - \left(\frac{\omega_2}{\omega_1}\right)^2 \delta_2 \right]$$

$$M_\alpha = -I\omega_1^{\,2} \left[ 1 - \left(\frac{\omega_2}{\omega_1}\right)^2 \right]$$

where $\omega$ = circular frequency, rad/sec

$\delta$ = log decrement, $\frac{1}{n} \ell n \frac{\alpha_{initial}}{\alpha_{final}}$

$n$ = number of cycles

subscript$_1$, wind-on conditions

subscript$_2$, wind-off conditions

For a model of given moment of inertia and oscillation frequency, the accuracy with which $M_q + M_{\dot{\alpha}}$ can be obtained is governed by whether or not the quantity $\left[\delta_1 - \left(\frac{\omega_2}{\omega_1}\right)^2 \delta_2\right]$ is a "large difference in small numbers" or "small difference in large numbers." Thus, by minimizing the structural damping of the supporting structure, $\delta_2$ will be minimized and the quantity $\left[ \delta_1 - \left(\frac{\omega_2}{\omega_1}\right)^2 \delta_2 \right]$, which is constant for a given model design and tunnel operating conditions, can be determined with the maximum accuracy from experiment. A typical result of amplitude history is shown in Figure 2. Note the structural damping is so low that it would take 3000 cycles to damp to half amplitude.

The first tests using this rig were made on a 5.6-degree blunted cone†. The results of these tests gave a value for the aerodynamic damping which was about one fourth of that predicted by Newtonian theory, while the restoring moment was in agreement with Newtonian. Other tests from AEDC on different configurations showed the aerodynamic damping to be in agreement with Newtonian theory, while the restoring moment was not. This anomaly stimulated a theoretical study based upon semiempirical pressure distributions on blunted cones, and upon a quasi-steady analysis. The results of this study, soon to be published as a technical note in the AIAA Journal*, explain experimentally observed deviation from Newtonian theory (Figure 3). Additional theoretical and experimental work is under way at ARL to give a better understanding of the phenomena of aerodynamic damping at high Mach numbers.

†*Walchner, Otto, F. M. Sawyer and S. J. Koob, "Dynamic Stability Testing in a Mach-14 Blowdown Wind Tunnel," Journal of Spacecraft and Rockets, Vol. 1, Nr. 4, 1964, p. 437.*

**Walchner, Otto and J. T. Clay, "An Analysis of the Stability Derivatives $C_{m_\alpha}$ and $C_{m_q}$ for Blunted Slender Cones at High Mach Numbers," (to appear in the AIAA Journal).*

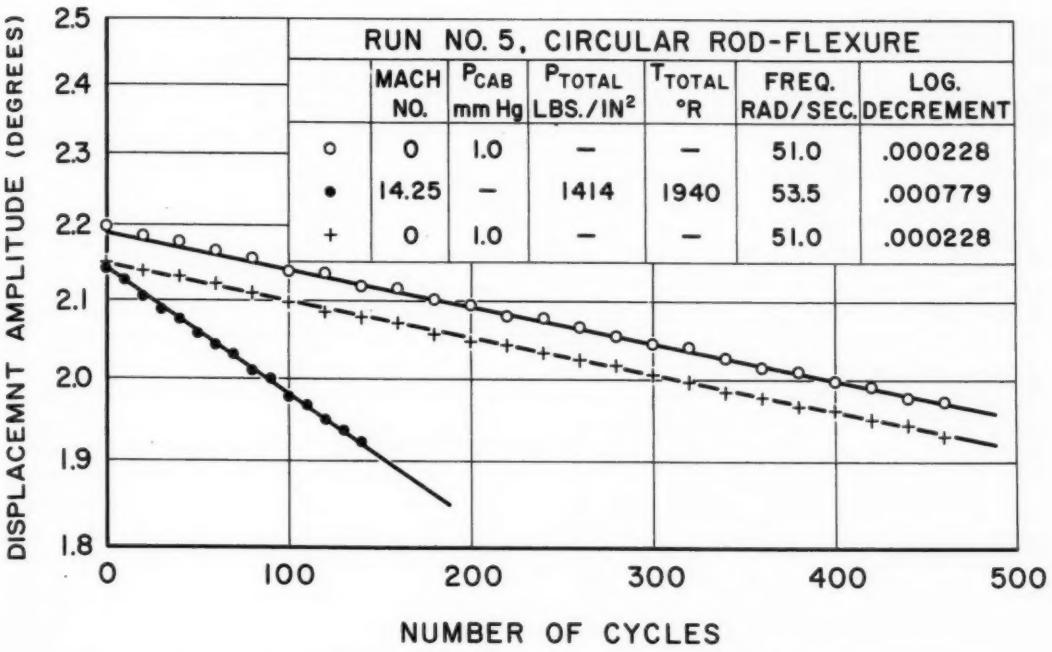



FIGURE 2. Amplitude Decay History of Cone Model for Both Wind-On and Wind-Off (Near-Vacuum) Conditions.

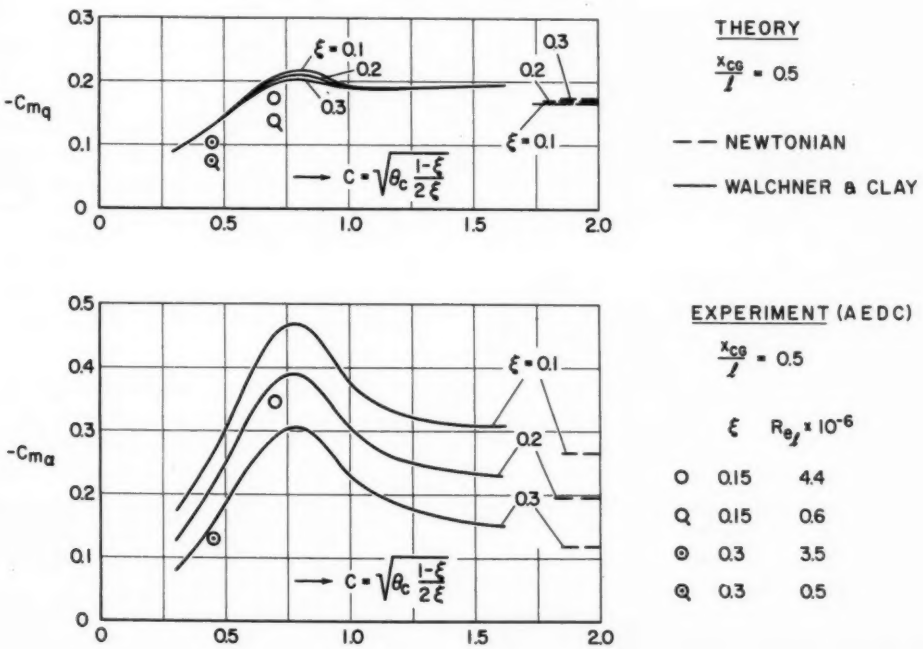
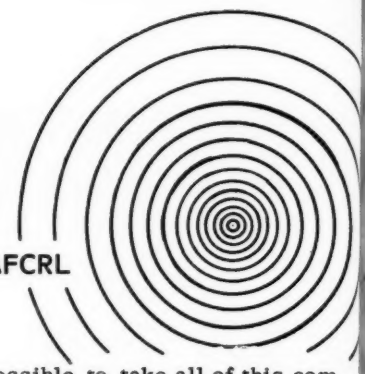



FIGURE 3. Stability Derivatives Versus Correlation Factor C for Both Theory and Experiment, $\xi = \frac{\text{Nose Radius}}{\text{Base Radius}}$

# EXTRACTING NUCLEAR-INDUCED SIGNALS FROM SEISMIC NOISE

DR NORMAN A. HASKELL, Terrestrial Sciences Laboratory, AFCRL



About the only way to detect an underground nuclear explosion occurring a great distance away is by seismic means. But the seismic wave form of the detonation must be differentiated from similar signals of small earthquakes. This means that all possible differences between the seismic signatures of earthquakes and explosions must be investigated for disgnostic criteria. Several agencies are working on this problem, one of which is AFCRL.

One approach being investigated at AFCRL is based on studying the radiation pattern of Rayleigh waves. These are elastic surface waves that occur only in solids. The displacement is greatest near the surface, and attenuates rapidly with depth. For a spherically symmetrical compressed source in a homogeneous medium, the radiation of Rayleigh waves should be the same in all directions. In the case of an earthquake, which results from slippage along a fault, the radiation is expected to vary in a systematic way with azimuth.

It is convenient to consider the seismic waves from an earthquake as originating from either two (single-couple) or four (double-couple) closely spaced radiating sources. As with radio transmissions from a multiple array, radiation is channelled along certain preferred directions. Thus, if the earth were homogeneous, it wouldn't be too difficult to distinguish between natural and nuclear-induced seismic wave forms. But the geological complexity of the earth's crust tends to scramble all acoustic wave forms, and absorption of the high-frequency components tends to wipe out the diagnostic details in the signal received over long distances.

It is not possible to take all of this complexity into consideration in a mathematical model; but, as a first approximation, the earth may be regarded as made up of a number of horizontally homogeneous parallel layers. In the AFCRL study, expressions have been derived for the azimuthal radiation pattern of Rayleigh waves from single- or double-couple sources of any given orientation at any depth in a horizontally layered medium.

Because of the idealizations necessary in any mathematical model, tests of the theory against real data are essential. In one such test, an AFCRL contractor digitally analyzed a number of seismograms from both earthquakes and explosions. After performing Fourier analysis and phase equalization at various azimuths, the following conclusions were drawn:

1) The radiation patterns of Rayleigh waves from underground nuclear explosions indicate that the source mechanism is an explosive force acting as a step function in time.

2) The collapse of the cavity, which follows many of the large explosions in alluvium and tuff, generates Rayleigh waves with reversed polarity relative to the explosion.

3) An explosion in granite produced a surface-wave radiation pattern with nearly perfect double-couple symmetry in both phase and amplitude (this type of pattern is expected from earthquakes, not explosions, and must have resulted either from cracking in some preferred direction, or the release of strain in nearby faults).

4) The amplitude and initial phase spectrum of Rayleigh waves are more complex for earthquakes than for explosions. ★

# TO OUR READERS

Requests for further information should be directed to the individual or laboratory of origin (except for those from Latin America).

Addresses are as follows:

**AIR FORCE CAMBRIDGE RESEARCH LABORATORIES**
Attn: CRI
Laurence G. Hanscom Field, Bedford, Massachusetts 01731

**AEROSPACE RESEARCH LABORATORIES**
Attn: ARB
Wright-Patterson Air Force Base, Ohio 45433

**AIR FORCE OFFICE OF SCIENTIFIC RESEARCH**
Attn: SRGL
Tempo D Building
4th and Independence Avenue, S.W., Washington, D.C. 20333

**OFFICE OF RESEARCH ANALYSES**
Attn: ORR
Holloman AF Base, New Mexico 88330

Requests for further information from institutions and individuals in Latin America should be addressed to:

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Detailed documentary reports may be obtained from:

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